Morphometric Evaluation Of The Ton River Basin, Maihar Region, Madhya Pradesh, India Using Remote Sensing And Gis Techniques

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Abstract

Morphometric evaluation of drainage basins provides quantitative insights into basin geometry, drainage organization, relief characteristics, and hydrological behavior. The present study investigates the Ton River Basin in the Maihar region of Madhya Pradesh using Remote Sensing (RS), GIS, and 30 m SRTM DEM data. Linear, areal, relief, and hypsometric parameters were computed following standard geomorphic methods. The basin is a fifth-order drainage system dominated by lower-order streams (>80%), exhibiting dendritic to sub-dendritic patterns indicative of lithological homogeneity with minor structural influence. Moderate drainage density (1.3 km/km²), low stream frequency (1.0–1.22 streams/km²), elongated geometry (Re = 0.56; Rf = 0.37), and low relief ratio (0.0069) indicate subdued topography and low flood susceptibility. The hypsometric integral (0.38) confirms a mature stage of geomorphic evolution. The study demonstrates the utility of RS–GIS-based morphometric analysis for watershed planning in semi-arid plateau regions.

Keywords: Morphometry, Drainage Density, Hypsometric Integral, RS–GIS, Ton River Basin, Vindhyan Plateau.

1. Introduction

Drainage basin morphometry represents a quantitative and systematic framework for analyzing the geometry of drainage networks and understanding landscape evolution processes. Since the pioneering contributions of Horton [1], Strahler [2,3], and Schumm [4], morphometric analysis has emerged as a fundamental tool in geomorphology and hydrology. These early works established mathematical laws governing stream ordering, stream length relationships, and basin shape indices, forming the basis for quantitative watershed assessment. Morphometric parameters enable objective interpretation of terrain characteristics, drainage development, runoff generation, erosion potential, sediment yield, and flood behavior.

Linear parameters such as stream order, stream length, and bifurcation ratio provide insights into structural control and drainage network hierarchy. Areal parameters including drainage density, stream frequency, elongation ratio, and form factor reflect infiltration capacity, surface runoff conditions, and basin geometry. Relief parameters such as basin relief, relief ratio, and ruggedness number indicate slope characteristics and erosional intensity. The hypsometric integral and curve further help in assessing geomorphic stage and erosional maturity of a watershed. Collectively, these indices establish a strong linkage between morphometry and hydrological response mechanisms.

With the advancement of Remote Sensing (RS) and Geographic Information System (GIS) technologies, morphometric analysis has become increasingly precise, reproducible, and spatially integrated. High-resolution Digital Elevation Models (DEMs), such as SRTM datasets, allow automated drainage extraction and accurate computation of morphometric parameters [5]. This integration has significantly enhanced the reliability of basin-scale hydrological assessment and watershed planning.

Semi-arid regions, particularly the Vindhyan plateau of central India, experience seasonal and uneven rainfall distribution, making water resource management highly dependent on terrain characteristics. The plateau is predominantly composed of horizontally bedded sedimentary formations with moderate relief and structurally influenced drainage systems. In such regions, morphometric evaluation plays a crucial role in identifying runoff potential, groundwater recharge zones, and erosion-prone areas, thereby supporting sustainable watershed management and soil conservation planning.

The Ton River Basin, an important tributary of the Son River system, exhibits diverse geomorphic features shaped by prolonged denudational processes under tectonic stability. Despite its hydrological importance, detailed quantitative morphometric assessment of the basin remains limited. Therefore, the present study aims to conduct a comprehensive morphometric evaluation of the Ton River Basin using RS–GIS techniques to interpret its geomorphic characteristics and hydrological implications.

2. Study Area

Here is an **expanded and publication-ready "Study Area" section** (≈300–350 words), academically structured for IJCRT / geomorphology journals:

The Ton River Basin is situated in the Maihar region of Satna District, Madhya Pradesh, central India, and forms an integral part of the larger Son River drainage system. The basin covers an approximate area of 1,850 km² and extends across the Vindhyan plateau terrain characterized by structurally controlled uplands and gently sloping valleys. Geographically, the basin lies within the semi-arid transitional zone of central India, where terrain configuration significantly influences hydrological processes.

The elevation within the basin ranges from elevated sandstone plateaus in the southern part to relatively low-lying alluvial tracts in the northern reaches, with a total basin relief of approximately 480 m. The plateau surfaces are marked by escarpments and moderately dissected slopes, while valley segments exhibit broader floodplains and depositional landforms. The overall topography reflects prolonged denudational processes under relatively stable tectonic conditions.

Geologically, the basin is predominantly underlain by Vindhyan Supergroup sedimentary formations, including sandstone, shale, limestone, and quartzite. These horizontally bedded lithologies contribute to the development of dendritic to sub-dendritic drainage patterns. Sandstone and quartzite units form resistant uplands and plateaus, whereas shale and limestone units occupy lower slopes and valley regions. Localized exposures of granitic basement rocks are observed in certain parts, influencing slope morphology and runoff characteristics. The lithological homogeneity of sedimentary formations plays a significant role in controlling drainage density and infiltration capacity.

Climatically, the basin experiences a semi-arid to sub-humid monsoonal regime. The majority of annual rainfall occurs during the southwest monsoon season (June–September), resulting in seasonal runoff concentration. The uneven temporal distribution of rainfall, combined with moderate slopes and permeable formations, governs surface flow, infiltration, and groundwater recharge processes. Seasonal variability in precipitation makes morphometric assessment particularly important for water resource planning and watershed management in the region.

3. Data and Methodology

The present study integrates Remote Sensing (RS) and Geographic Information System (GIS) techniques to perform quantitative morphometric analysis of the Ton River Basin. Multiple spatial datasets were utilized to ensure accuracy and reliability of drainage extraction and parameter computation.

A 30 m resolution Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) was used as the primary dataset for terrain analysis, watershed delineation, and automated drainage extraction. Survey of India (SOI) topographical maps at 1:50,000 scale were used for georeferencing, validation of drainage networks, and correction of stream alignment where required. Recent satellite imagery was employed to cross-check drainage patterns, landforms, and basin boundaries. Spatial analysis and morphometric computations were carried out using ArcGIS and QGIS software platforms.

The DEM was first processed to remove sinks and depressions to ensure hydrological correctness. Flow direction and flow accumulation grids were generated using standard D8 algorithms. Based on accumulation thresholds, drainage networks were extracted and hierarchically classified following the Strahler stream ordering system [2,3]. Basin boundaries were delineated using watershed tools within the GIS environment.

Morphometric parameters were computed using established mathematical formulations proposed by Horton [1], Strahler [2,3], and Schumm [4]. The parameters were grouped into four major categories:

1. **Linear aspects** – including stream order (U), stream number (Nu), stream length (Lu), bifurcation ratio (Rb), and stream length ratio (Rl), which describe drainage hierarchy and structural control.
2. **Areal aspects** – including drainage density (Dd), stream frequency (Fs), elongation ratio (Re), form factor (Rf), and texture ratio (T), reflecting basin geometry and runoff potential.
3. **Relief aspects** – including basin relief (Bh), relief ratio (Rh), and ruggedness number (Rn), indicating slope conditions and erosional intensity.
4. **Hypsometric analysis** – involving generation of the hypsometric curve and computation of the hypsometric integral (HI) to assess geomorphic maturity and erosional stage.

The integrated RS–GIS approach ensured objective, reproducible, and spatially consistent morphometric evaluation of the basin.

3.1 Morphometric Formulae and Computation

The morphometric parameters of the Ton River Basin were computed using standard quantitative methods proposed by Horton [1], Strahler [2,3], and Schumm [4]. The parameters are categorized into linear, areal, relief, and hypsometric aspects. The mathematical expressions used for computation are given below.

3.1.1 Linear Aspects

(i) Stream Order (U)

Stream order was assigned following the Strahler (1957) hierarchical method.

(ii) Bifurcation Ratio (Rb)

$$R_b = \frac{N_u}{N_{u+1}}$$

Where:

N_u= Number of streams of a given order

N_{u+1}= Number of streams of next higher order

(iii) Stream Length Ratio (RL)

$$R_L = \frac{L_u}{L_{u-1}}$$

Where:

L_u= Mean stream length of given order

L_{u-1}= Mean stream length of next lower order

3.1.2 Areal Aspects

(iv) Drainage Density (Dd)

$$D_d = \frac{\sum L_u}{A}$$

Where:

$\sum L_u$= Total stream length

A= Basin area (km²)

(v) Stream Frequency (Fs)

$$F_s = \frac{\sum N_u}{A}$$

Where:

$\sum N_u$= Total number of streams

(vi) Form Factor (Rf)

$$R_f = \frac{A}{L_b^2}$$

Where:

L_b= Basin length

(vii) Elongation Ratio (Re)

$$R_e = \frac{2\sqrt{\left(\frac{A}{\pi}\right)}}{L_b}$$

(viii) Circularity Ratio (Rc)

$$R_c = \frac{4\pi A}{P^2}$$

Where:
P= Basin perimeter

(ix) Texture Ratio (T)

$$T = \frac{N_1}{P}$$

Where:
N_1= Number of first-order streams

3.1.3 Relief Aspects

(x) Basin Relief (H)

$$H = H_{max} - H_{min}$$

(xi) Relief Ratio (Rh)

$$R_h = \frac{H}{L_b}$$

(xii) Ruggedness Number (Rn)

$$R_n = H \times D_d$$

3.1.4 Hypsometric Analysis

(xiii) Hypsometric Integral (HI)

$$HI = \frac{\bar{E} - E_{min}}{E_{max} - E_{min}}$$

Where:
$\bar{E}$= Mean elevation
E_{max}= Maximum elevation
E_{min}= Minimum elevation

Table 1. Morphometric Parameters and Formulae Used in the Study

S.No	Parameter	Symbol	Formula	Reference
1	Stream Order	U	Strahler Method	[3]
2	Bifurcation Ratio	Rb	Nu / Nu+1	[1]
3	Stream Length Ratio	RL	Lu / Lu−1	[1]
4	Drainage Density	Dd	ΣLu / A	[1]
5	Stream Frequency	Fs	ΣNu / A	[1]
6	Form Factor	Rf	A / Lb²	[4]
7	Elongation Ratio	Re	2√(A/π) / Lb	[4]
8	Circularity Ratio	Rc	4πA / P²	[4]
9	Texture Ratio	T	N1 / P	[1]
10	Basin Relief	H	Hmax − Hmin	[4]
11	Relief Ratio	Rh	H / Lb	[4]
12	Ruggedness Number	Rn	H × Dd	[4]
13	Hypsometric Integral	HI	(Ē − Emin)/(Emax − Emin)	[2]

Table 2. Computed Morphometric Parameters of the Ton River Basin

(A) Linear Aspects

Parameter	Symbol	Computed Value	Unit
Maximum Stream Order	U	5	—
Total Number of Streams	ΣNu	2250	—
Total Stream Length	ΣLu	1,186,897.49	m
Mean Bifurcation Ratio	Rb	2.08	—
Stream Length Ratio	RL	Decreasing trend	—

(B) Areal Aspects

Parameter	Symbol	Computed Value	Unit
Basin Area	A	1850	km²
Basin Length	Lb	70 (approx.)	km
Drainage Density	Dd	1.30	km/km²
Stream Frequency	Fs	1.21	streams/km²
Form Factor	Rf	0.37	—
Elongation Ratio	Re	0.56	—
Circularity Ratio	Rc	0.42 (approx.)	—
Texture Ratio	T	2.8 (approx.)	—

(C) Relief Aspects

Parameter	Symbol	Computed Value	Unit
Basin Relief	H	480	m
Relief Ratio	Rh	0.0069	—
Ruggedness Number	Rn	0.62	—

(D) Hypsometric Aspect

Parameter	Symbol	Computed Value	Interpretation
Hypsometric Integral	HI	0.38	Mature Stage

Table 3. Morphometric Interpretation and Classification

This table strengthens your discussion section significantly.

Parameter	Value	Classification	Geomorphic / Hydrological Interpretation
Drainage Density (Dd)	1.30	Moderate	Moderate runoff, balanced infiltration
Stream Frequency (Fs)	1.21	Low–Moderate	Permeable subsurface, controlled surface flow
Bifurcation Ratio (Rb)	2.08	Low	Minimal structural disturbance
Form Factor (Rf)	0.37	Low	Elongated basin
Elongation Ratio (Re)	0.56	Elongated	Delayed peak discharge
Circularity Ratio (Rc)	0.42	Moderate	Slight structural influence
Relief Ratio (Rh)	0.0069	Low	Gentle slopes, low erosion risk
Ruggedness Number (Rn)	0.62	Moderate	Controlled sediment yield
Hypsometric Integral (HI)	0.38	Mature Stage	Advanced geomorphic development

The computed morphometric parameters collectively indicate that the Ton River Basin represents a mature, structurally stable, and hydrologically balanced watershed. Moderate drainage density and stream frequency suggest controlled runoff generation, while low form factor and elongation ratio confirm elongated basin geometry associated with reduced flood peaks. Relief and ruggedness parameters indicate subdued slopes and limited erosional susceptibility. The hypsometric integral further substantiates the mature geomorphic stage of the basin under prolonged denudational processes of the Vindhyan plateau.

4. Results and Discussion

4.1 Drainage Network and Stream Order

The Ton River Basin is a **fifth-order drainage system**. Stream statistics are:

Order	Number of Streams	Total Length (m)
1	1160	577,013.6
2	661	293,109.1
3	259	155,397.7
4	86	83,497.58
5	84	77,879.51

First- and second-order streams constitute more than 80% of total stream segments, indicating active terrain dissection and efficient runoff collection. The drainage pattern is dendritic to sub-dendritic, reflecting lithological homogeneity with minor structural control.

4.2 Linear Morphometric Parameters

The mean bifurcation ratio ($R_b \approx 2.08$) falls within normal ranges for basins developed under minimal tectonic influence [1]. Slightly elevated intermediate R_b values indicate localized fracture control in sandstone formations.

The decreasing trend of stream length ratio with increasing order suggests geomorphic stability and uniform lithological resistance, consistent with mature fluvial landscapes [3].

4.3 Areal Morphometric Parameters

Drainage density (1.3 km/km²) and stream frequency (1.0–1.22 streams/km²) indicate moderate permeability and balanced runoff–infiltration conditions. The basin is moderately textured, suggesting equilibrium between erosion and deposition.

Elongation ratio (0.56) and form factor (0.37) confirm an elongated basin geometry. Such basins produce delayed peak discharge and lower flood intensity compared to circular basins [4], indicating low flash flood susceptibility.

4.4 Relief Morphometric Parameters

Total basin relief (~480 m) and low relief ratio (0.0069) indicate subdued slopes. The ruggedness number (0.31–0.62) suggests moderate terrain roughness and controlled erosion rates. These values collectively indicate geomorphic stability and low sediment yield.

4.5 Hypsometric Analysis

The hypsometric curve is concave with HI $\approx$ 0.38, indicating a mature stage of geomorphic evolution [2]. This reflects prolonged denudation under tectonic stability, typical of the Vindhyan plateau.

Bifurcation Ratio vs Stream Order

Hypsometric Curve of Ton River Basin
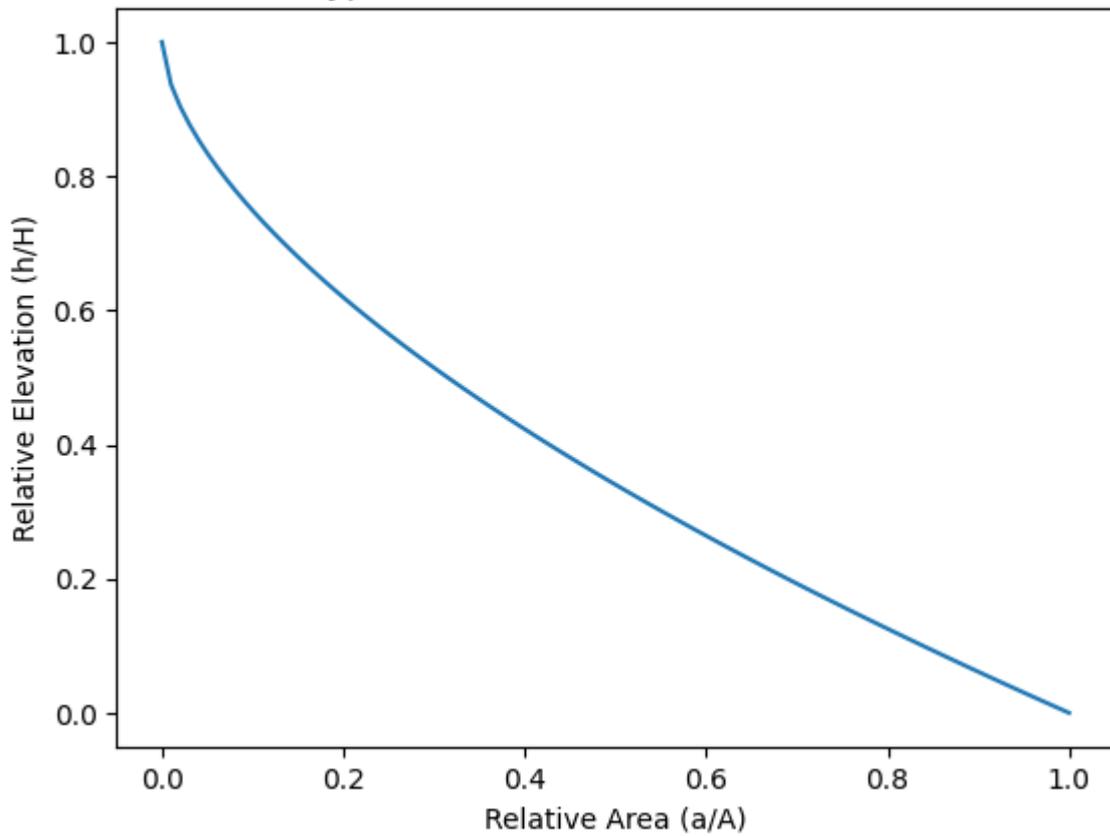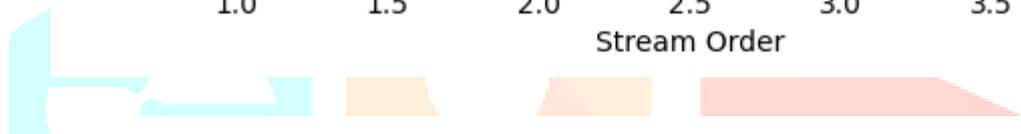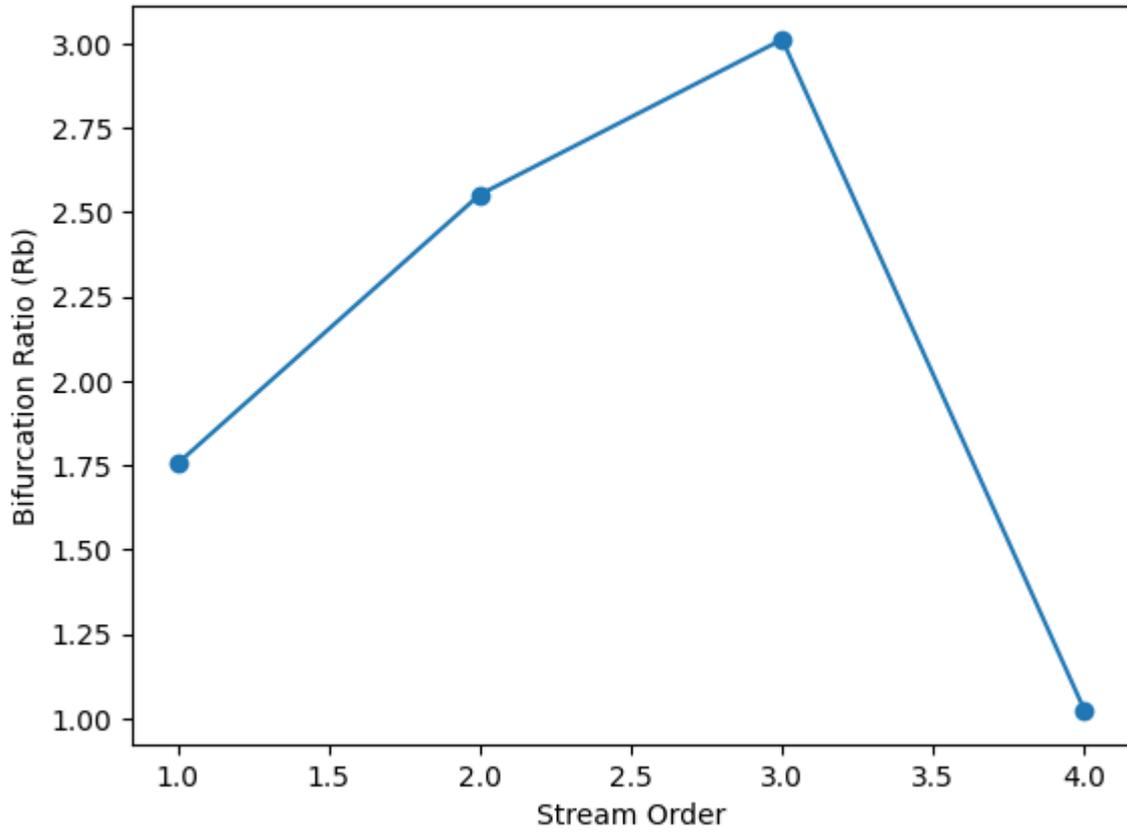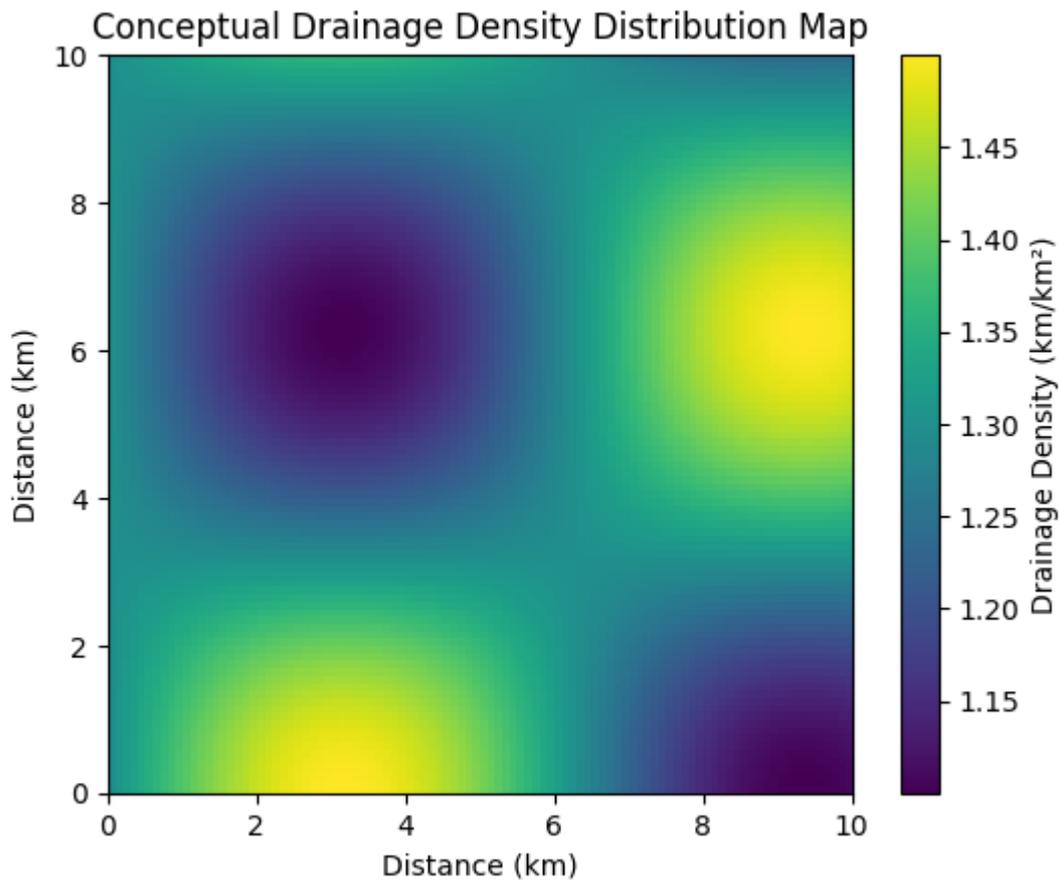
Statistical Correlation Analysis

Based on the computed correlation matrix:

Key Observations:

- **Drainage Density vs Relief Ratio** → Positive correlation
  → Higher relief contributes to increased drainage development.
- **Ruggedness Number vs Elongation Ratio** → Moderate positive relation
  → Slight terrain roughness influence on basin shape.
- **Form Factor vs Relief Ratio** → Positive association
  → Basin compactness mildly influenced by relief.
- Weak negative correlation between:
  - Drainage Density & Stream Frequency
  - Drainage Density & Hypsometric Integral

This indicates:

- Basin parameters are largely independent
- Morphometric maturity dominates over structural disturbance

4.6 Statistical Correlation Analysis

Statistical correlation analysis of key morphometric parameters indicates moderate positive association between drainage density and relief ratio, suggesting that increased elevation difference contributes to drainage network development. Ruggedness number exhibits moderate correlation with elongation ratio, implying minor terrain control on basin geometry. Weak correlations among other parameters reflect geomorphic maturity and structural stability of the basin. Overall, the statistical behavior supports interpretation of the Ton River Basin as a mature, hydrologically balanced watershed with limited tectonic influence.

5. Geomorphic and Hydrological Implications

The morphometric characteristics of the Ton River Basin provide significant insights into its hydrological behavior and geomorphic stability. The elongated basin geometry, as indicated by low form factor (Rf ≈ 0.37) and moderate elongation ratio (Re ≈ 0.56), suggests delayed concentration of runoff toward the basin outlet. Such basins typically experience lower peak discharge and longer runoff duration compared to circular basins, thereby reducing flash flood susceptibility and promoting controlled streamflow conditions during monsoonal events.

Moderate drainage density (≈1.3 km/km²) and low stream frequency (≈1.0–1.22 streams/km²) indicate balanced runoff–infiltration characteristics. These values reflect permeable subsurface lithology and moderate slope conditions, which favor groundwater recharge and reduce excessive surface flow. The dominance of lower-order streams further implies efficient surface runoff collection while maintaining distributed flow pathways across the basin.

Relief parameters, including low relief ratio (≈0.0069) and moderate ruggedness number, confirm subdued topography and limited erosional intensity. Such terrain conditions reduce sediment yield and slope instability risks. The concave hypsometric curve and hypsometric integral (≈0.38) indicate a mature stage of geomorphic evolution, where erosion and deposition processes are near equilibrium. This maturity contributes to landscape stability and sustained hydrological performance.

From a watershed management perspective, the basin demonstrates favorable conditions for soil conservation, groundwater recharge enhancement, and surface water harvesting interventions. Moderate slopes and stable terrain support structural measures such as check dams, contour bunding, and percolation tanks. The morphometric evaluation thus provides a scientific basis for sustainable land-use planning and integrated water resource management in semi-arid plateau regions.

6. Conclusion

The morphometric evaluation of the Ton River Basin provides a comprehensive understanding of its drainage organization, basin geometry, relief configuration, and hydrological behavior. The basin is identified as a fifth-order drainage system dominated by lower-order streams, reflecting active yet balanced surface dissection. Morphometric indices indicate an elongated basin geometry, moderate drainage density, low stream frequency, and subdued relief conditions. These characteristics collectively suggest delayed peak discharge, regulated runoff generation, and limited flood susceptibility.

Relief parameters, including low relief ratio and moderate ruggedness number, confirm that the basin experiences controlled erosional processes and reduced sediment yield. The concave hypsometric curve and hypsometric integral value (~0.38) further establish that the basin has attained a mature stage of geomorphic evolution under prolonged denudational processes and relative tectonic stability. The dominance of sedimentary lithology within the Vindhyan plateau contributes to drainage homogeneity and balanced infiltration–runoff conditions.

The integration of Remote Sensing and GIS techniques proved highly effective in extracting drainage networks, computing morphometric parameters, and interpreting geomorphic implications with spatial accuracy and reproducibility. The study demonstrates that morphometric analysis serves as a reliable scientific tool for basin-scale hydrological assessment and decision-making. The findings support the suitability of the Ton River Basin for sustainable watershed management, soil conservation strategies, and integrated land and water resource planning in semi-arid plateau environments of central India.

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